Digital materiality: emergent computational fabrication

Peter Booth

University of Tasmania, Launceston, Australia

ABSTRACT: Fundamentally architecture is a material-based practice that implies that making and the close engagement of materiality is intrinsic to design process. With the rapid uptake of new computational tools and fabrication techniques by the architectural profession there is potential for the connection between architecture and materiality to be diminished. Innovative digital technologies are redefining the relationship between design and construction encoding in the process new ways of thinking about architecture. A new archetype of sustainable architectural process is emerging, often cited as Digital Materialism.

Advanced computational processes are moving digital toolsets away from a representational mode towards being integral to the design process. These methods are allowing complex design variables (material, fabrication, environment, etc.) to be interplayed within the design process, allowing an active relationship between performative criteria and design sustainability to be embedded within design methodology.

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INTRODUCTION

Emergent modes of digital architecture are radically transforming current processes of design and construction. Advanced software is offering architects the possibility of interplaying a multitude of performance-based variables within the design process itself and, for the first time, allowing for real time feedback and analysis of generated propositions. The use of computer numerically controlled (CNC) fabrication is offering the capacity to realise and construct the amorphous surfaces and complex geometries that often result from emerging modes of architectural computation. At an astonishing rate new computational technologies are pushing the boundaries of architectural style further away from its roots in post-modernism. However, for architecture to continue to evolve at the current rate it must consider the effect that advanced modes of fabricational computation is having on the materiality of architecture itself.

1.0 MATERIAL PRACTICE

At its core, architecture is a material-based practice that implies that making and the close engagement of materiality is intrinsic to a design process. This was more strongly evident in traditional modes of architecture in which the role of master-builder was assumed, a role that has long since disappeared in terms of the current architect. The introduction of steel and factory based manufacturing processes were perhaps the turning point in the diminishing of traditional notions of architectural materiality. As personalisation became more labour intensive and costly due to the favouring of mass production, designers, builders and manufactures became more segregated, fragmenting technical specialization and knowledge (Henriques 2009). This allowed for each to advance rapidly, but in isolation and with little input from other fields, leading to a design environment in which architects are spoilt for material choice, but understand little about the actual material itself. More significantly, the disassociation of knowledge in the field, along with an increase in litigation, has created an environment in which architects have diminished the importance of their own involvement in the act of construction (Kolarevic 2005)

Conversely, the adoption of factory fabricated mass-produced items for the construction industry (amongst others) has seen the emergence of new fabrication tools that are beginning to redefine the relationship between design and construction. CNC fabrication machines, commonly found in joinery workshops, are allowing the delivery of customised joinery with the speed and cost efficiencies usually found in a mass-production environment. In addition to being capable of creating custom joinery studios *en masse*, they have the capacity to significantly alter and enhance the relationship between architect and material through the means of digital fabrication.

The engagement with digital fabrication technologies is rapidly being adopted by leading international practices including, Gehry Partners, Greg Lynn and Herzog de Meuron. The acceptance of leading edge manufacturing, in addition to powerful emerging software, is establishing an environment in which architecture is rediscovering itself as a material based practice. The new processes of architectural manufacturing rely upon the seamless digital integration from conception through to construction. It is now CNC machines and not the hands of skilled craft persons that shape the material form of architecture. Innovative digital technologies are redefining the relationship between design and construction, encoding in the process new ways of thinking about and making architecture.

But what are the new grounds of architectural materialism? Digital modes of fabrication are requiring architects to reconsider their understanding of how buildings are controlled and created, even from the very initial stages of design. Shifting away from the 'off-the-self' mentality of the construction industry that we saw during the 20th Century, the opportunity is now available for completely custom material expression to be employed with little or no additional cost. Gehry's work has shown a strong understanding of software, materials and fabrication can produce extraordinary results for comparable expenditure (Glymph 2003).

Moving on from Gehry's work, new wave architects such as Zaha Hadid, UNStudio and Ross Lovegrove, are pushing digital materialism even further. Rosa discusses their work in terms of a 'material elegance', offering a 'matured sense of production that informs and merges materiality with formal qualities' (Rosa 2007). He proposes that material elegance not only address issues of aesthetics and subjectivity, but establishes a new direction of thinking and about production of architecture itself.

Leach suggests that Digital Materialism moves away from a view in which object production is seen as a symbolised form towards a state in which objects are seen to become expressive (Leach 2009). This shift away from representational modes of form implies that material expression should somehow communicate the means in which it came into fruition. In an architectural sense this would suggest that buildings and objects should recapture the materiality that has been lost during the mass-produced period, expressing the true nature of architectural fabric and construction. In terms of the digital environment that materials encounter today, it is the inherent understanding of material and fabricational variables and capacities that empowers new modes of digital materialism.

2.0 PERFORMANCE BASED METHODOLOGIES

Much of early digital architecture was that of a traditional top down approach in that "[the] objective here was simply to use the computer to make the designs of the architect realizable." (Leach 2009). Form and surface were specifically designed at the outset and computational tools were utilized to realise and adhere to the original intent. In some examples the curvature that was anticipated ended up as a triangulated panel system, in turn loosing the fluidity and smoothness that was originally intended. A contributing factor towards this was that the material, computational and machine based design parameters were overlooked and not introduced to the design process at an early enough stage.

Conversely, new digital design methodologies have evolved which integrate performance-based design criteria (material, machine, etc.) into the process itself. The Emergent Design Group, originating at the Architectural Association in London, have researched and published widely in this area of design methodology, often referring to it as digital morphogenesis. Kolarevic advocates that this mode of morphogenesis refers to a bottom-up methodology in which the architect has the capacity control over the computational aspects of the process (Kolarevic 2003).

It is this morphogenetic methodology that allows for the interplay of design variables throughout all stages of a design process. In the context of the academic investigation, each stage (surface, material, machine and mould) of the process offered its own array of specific constrain and opportunity. A decision in relation to the mould material has variable influence on the machining conditions; the specific cutting tool has a direct and alterable effect on the mould and the pattern, and so on. The vast array of possible intermeshing of parameters at all stages of a design process establishes a fertile environment in which digital materialism can be investigated.

3.0 ACADEMIC INVESTIGATION

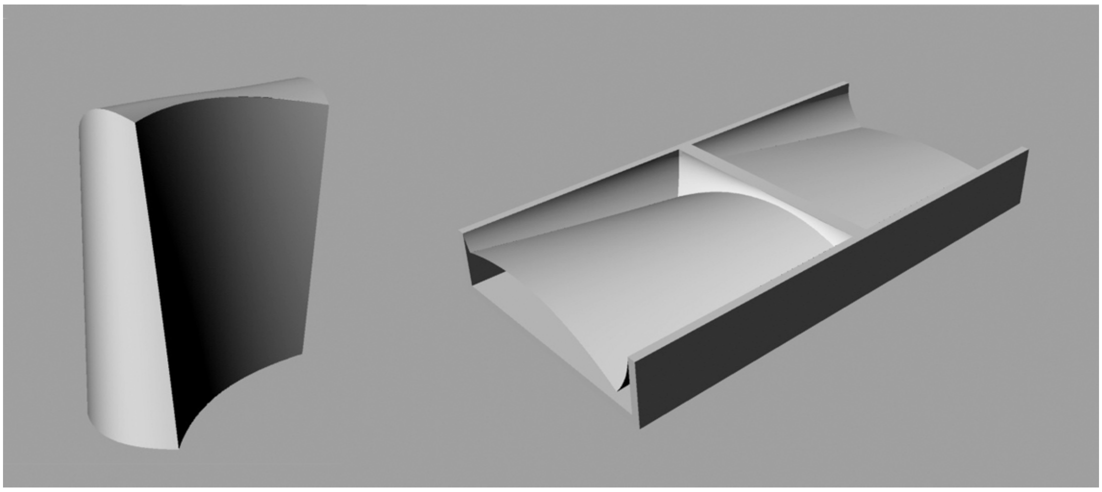
3.1 Proposition

Established as an elective studio in free form modelling for second and third year students, the primary objective of the studio was to accommodate the development of core skills within a software environment. Moving away from a traditional visual representation approach specific focus was placed upon the transition from virtual to physical environments. This allowed the scope of the studio to encompass and expand upon the School's already strong experience in architectural fabrication. The integration of fabrication requirements provided scope for additional investigation specifically relating to performative material and machine processes, which are often overlooked when free-from (form) modelling is treated in isolation. This inclusion allowed students to consider the implications of free-form modelling in a construction context.

Students were asked to develop an architectural 'object' that would facilitate exploration of both virtual and physical techniques. Specific focus was placed upon the links between digital expression, material conditions and CNC/fabrication execution. In a similar fashion to Bernard Cache's *objectile* panels (Kolarevic and Klinger 2008), students were encouraged to develop both digital surfaces and machining tool paths to gain full control of the fabrication process. The CNC machined polystyrene was utilised as a mould, which would then be used to create an aesthetic concrete object. This would allow students to gain a skill set, and appreciation for, the process of digital fabrication and its influence on materials at an architectural scale.

3.2 Surface Condition

Rhinocerous 3D 4.0 (Rhino3D) was chosen as the software platform for the project. Specializing in Non-Uniform Rational B-Spline (NURBS) modelling, Rhino3D provides a CAD environment in free form and 'organic' forms can be engaged with freely, while still providing a high level of control and precision over the generated forms. In addition, Rhino3D offers a wide 2D tool set that seamlessly interacts with the 3D surface generation component. For example, 2D line work can be projected onto previously generated surface allowing the creation of intricate 3D patterns that can be utilised later in the process. Conversely, complex 3D surfaces could be described and built from a series of 2D lines.



Source: (Author 2009)

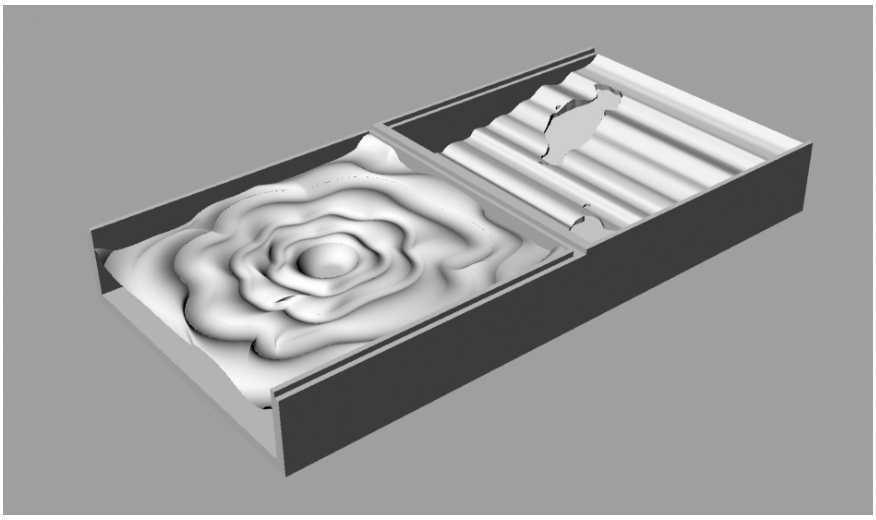
Figure 1: Simple digital surface topology and unfolded halves of mould.

As the object was to be cast in concrete, particular care had to be taken when creating the digital model. The mould would need to be made in a minimum of two parts in order to be easily removed from, and potentially reused for future production runs. Ideally the object would be contoured and formed to ensure that during the striking process no parts of the mould were trapped within the solid concrete surface, in the same manner that pattern makers in foundries do.

3.3 Mould condition

For 3D surface milling and visualisation, VisualMILL5.0 was used. This offered the opportunity for students to develop skills in the translation of surfaces from a digital environment to a physical one, bypassing the sharp learning curve of other milling application. Students were encouraged to have hands-on engagement with all stages of the fabrication process to ensure that a developed understanding of physical parameters was gained. VisualMILL offers the capacity not only to produce the machine code (g-code) that drives the CNC machine, but also visualise the effect that each stage of the process will have on the material. Significantly, this stage required students to conceptualise both the intricate surface of the mould and the resulting concrete object, noting that a CNC cutting tool would have the inverse effect at the concrete pattern stage.

VisualMILL offers the capacity to develop automated machining paths from a built-in library at a basic level. For more advanced operations it provides the capability to completely control the machining operations by importing line work that will form tool paths or setting machining regions allowing areas to be treated differently. Students quickly discovered the ramifications of their modelling choices at earlier stages of the process. Figure 1 illustrates a simple base topology designed to utilise the machining process as a key design driver. Figure 2 however, demonstrates a highly designed surface containing greater complexity and intricate details which will inevitably require very fine, and time consuming, milling to achieve the desired design input. In short, Figure 1 allows the digital machining to influence the product, while Figure 2 forces the machining process to a prescribed form.



Source: (KDA345: Soo Ken Keong & Wan Hoe Goh ,2009)

Figure 2: Complex digital surface topology

Prior to this project the School has mainly used the3-axis CNC machine for creating architectural follies and structures, predominately from 2D machining operations and sheet-based materials. In this studio 3D surface based machining was to be utilized in addition to a volume based material. Expanded polystyrene (EPS) was selected as the mould material, primarily for its cost and ease of machining. In comparison to 2D machining, 3D operations take a significantly greater length of time to complete and EPS offers a medium that can be machined smoothly at high speeds.

The School's CNC machine has the ability to work with material sizes of up to 1200x2400x200mm. Of these factors it is the 200mm cut depth limit that was significant for the project. Students were provided with a slab of EPS 1200x600x150mm which allowed a final maximum pattern size of 560x580x260mm. A 20mm perimeter was allowed for in the machining process in order to hold the concrete within the mould. The sizing of the pattern was selected to accommodate the limitations of the CNC machine and material, both of which were fine-tuned to allow for maximum freedom within the project constraints.

The CNC Machines size played an important role in selecting the correct materials, but in terms of finished effect much finer detail is embedded within a digital fabrication process. The most significant point of influence a CNC machine has on a material is the cutting tool. The profile and depth of the cutting tool has a major impact on the overall finished surface. A selection of tool profiles (flat, ball and veining) and sizes (6.35mm, 12mm, 24mm and 32mm) were chosen for the project to allow for wide variety of surface effects. A limited range of the cutting tools also permitted the use of the CNC machines auto-tool changer, offering the capacity to rapidly change milling variables at various stages within the machining process.

Source: (Author 2009)

Figure 3: Comparison of surface and machining techniques.

Figure 3 demonstrates the widely varying results from the machining process itself. The example on the left utilised a simple base to create a result that embeds and maximises the material fabrication process within surface itself. The example to the right used the exact opposite of this process, in that it started with a complex form and, in order to convey the original intent of the design, had to rely upon simplistic machining operations (fine grained parallel finishing).

3.4 Concrete Condition
The concrete, generously donated to the studio by Boral Concrete, was a specific mix designed for this project. Due to the fine detail inherent in the EPS moulds, fine aggregates were maximised to create a wet mix that would work its way into the mould details. Plasticisers were also added to ensure that the wet mix didn't loose strength due to high water content and as no additional reinforcement was included within the moulds.

Prior to commencing the project, a small-scale proof of concept was created that helped isolate foreseeable problems and resolutions. It was decided that a release agent should be used on the mould before coming into contact with the concrete to ensure that it would strike freely. Due to material delivery problems, canola oil was used as the releasing agent in lieu of a more high-tech product. To the studios' surprise, this proved to work very effectively as the oil filled the tiny divots between the balls in the EPS, allowing the concrete to release from the mould reasonably easily. When the time came to pour the concrete in all 11 moulds, the high-tech release agent had arrived. After curing for 10 days however, huge problems were encountered in striking the mould from the concrete. Figure 4 illustrates the comparison between proof of concept and first production run. Despite the complete destruction of the mould at the production stage, the concrete patterns survived with no damage.

Source: (Author 2009)
Figure 4: Successful proof of concept and not-so-successful production run.

After some investigation it was determined that this was a two-part problem. Firstly, the high-tech release agent came in a spray pack and its application created a very fine film over the moulds' surface. It appears that its thickness was not sufficient enough to fully fill the divots in the EPS. Secondly, as the surface area of the mould increased, there is inherently more suction force between the concrete and the mould. Even the moulds that were specifically designed to limit the amount of suction had to be completely destroyed during the removal process. In future investigations alternative materials and release agents could be considered and proven solutions at a proof-of-concept stage should be followed through to production to ensure continuity.

3.5 Completed Patterns
The cast concrete objects required a little finishing work to remove the remnant EPS from the surface. In most instances, this was achievable by using a high pressure water hose. Figure 5 illustrates a selection of the final concrete patterns. It is apparent that individual groups chose at an early stage whether to design a complex or simple surface and that this had a direct relationship to the final objects material expression.

Source: (Author 2009)

Figure 5: Final concrete objects, demonstrating varying level of surface finish.

What astounded the group was the maintained level of detail that was transferable throughout the process; from the topological surface to tool path processing, the EPS machining, and the final concrete pattern. In student critiques of their own work many suggested that had they known the level of machine input and detail that would be achievable they would have approached the project in a significantly different manner, concentrating on the material and machining craft rather then creating the ‘wow’ object from the projects conception.

CONCLUSION

At the outset, it is apparent that the studio has developed students capacity to explore digital and fabrication methodologies at a level at which they are often not exposed. Looking deeper into the body of work a higher level of thinking and execution is evident in the majority of projects. These explorations successfully investigated the transition between digital and physical environments, embedding a degree of digital materialism that saw intrinsic connections between process and performative fabrication parameters considered throughout the methodology.

While the computational aspect of the studio remained partly static, future research looks to develop design based pedagogy that allow for performance based material and fabrication variables to be embedded and visualised live throughout the process, offering a greater comprehension and empowerment of digital materialism and its role in contemporary design and architecture.

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